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COORDINATES OF U. S. NAVAL OBSERVATORY INSTALLATIONS

by

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This *Circular* provides a comprehensive discussion of the positions of the U.S. Naval Observatory instruments together with a general description of the coordinate systems employed. The geodetic background material has been assembled over an extended period, and does not take account of significant advances in the development of geodetic systems since April 1973. The manuscript was completed in February 1975.

COORDINATES OF U.S. NAVAL OBSERVATORY INSTALLATIONS

Introduction

This *Circular* embodies the final report of a committee established for the purpose of collecting and examining the diverse sources and values of the coordinates of the various Naval Observatory installations. As a result of the ensuing effort new values for previously published astronomical coordinates have been established, and in addition, values of geodetic coordinates referred to various datums have been gathered or calculated.

The committee consisted of the following members:

James A. Hughes (Chairman)
Peter Espenschied
Dennis McCarthy
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The material is arranged as follows:

- I. Historical Background
- II. Description of Coordinate Systems
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    - B. Old Naval Observatory, Washington, D.C.
    - C. Time Service Substation, Richmond, Florida
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- IV. Appendices
    - A. Astronomical coordinates of PZT #3 (Washington) and PZT #2 (Richmond)
    - B. Transformation of geodetic coordinates from one datum to any other
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    - F. Location of antennas used in time signal monitoring, Washington and Richmond
    - G. Some historical notes
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The historical discussions are certainly not exhaustive, nor are the descriptions of the coordinate systems intended to be complete. For the former, basic source material may be found in the Bibliography, while for the latter any of several texts in astronomy or geodesy contain full descriptions of the types of coordinate systems. Some of these texts are included in the Bibliography.

I. Historical Background

The coordinates of the Naval Observatory at Washington published in the *American Ephemeris* (*AE*) since the edition for 1898 have been the coordinates of the center of the clock house (Bldg. No. 3) located at the center of the circular reservation. Astronomical observations were and are made at other locations, but the results have usually been corrected to the center of the clock house.

The Naval Observatory was originally located at 23rd and E Streets in northwest Washington, D.C., but was removed to the present site at 34th Street and Massachusetts Avenue in 1893. These two locations are referred to as the 'old' and the 'new' site respectively.

The first determination of the astronomical longitude and latitude of the new Naval Observatory (NAVOBSY) was made in February 1893 by J. R. Eastman and A. N. Skinner who observed the differences in longitude and latitude between the old and new sites by observing meridian transits and zenith distances of stars simultaneously at the two sites, using telegraph keys connected to the same chronograph [1]. The observed differences, $\Delta\lambda = +3^s.670 \pm 0^s.018$, and $\Delta\phi = +1' \ 35''.88 \pm 0''.035$ (mean errors), were added to the coordinates which had been adopted for the old site. The resulting values for the new site:

$$\lambda = 5^h \ 08^m \ 15^s.71 \text{ W}$$
$$\phi = 38^\circ \ 55' \ 14''.68 \text{ N}$$

were published in the *AE* through the edition for the year 1900.

The U.S. Coast and Geodetic Survey (USC&GS) made a new determination of the astronomical longitude in 1897, connecting the old and the new observatories by a telegraph link through the USC&GS office on 14th Street [2]. They obtained a value of $15^s.78$ for the longitude of the clock house. (Note: The larger units of longitude and latitude will be omitted throughout this *Circular* when to do so causes no ambiguity.) This value was published in the *AE* from 1901 through 1968. A new value, 15.73, based upon the longitude adopted for Photographic Zenith Tube No. 3 (PZT #3) during the period 1962 through 1968 was introduced in the 1969 volume.

Historically all longitudes published as longitudes of Washington PZT instruments have actually referred to the longitude of the clock house. The longitudes of the clock house used for PZT #3 in the past, sometimes called 'conventional' or 'effective' longitudes, are:

	s
14 April 1956 to 31 December 1960	15.780
1 January 1961 to 31 December 1961	15.740
1 January 1962 to 31 December 1968	15.729
1 January 1969 to the present	15.7494

A measured difference, $-0^s.0400$, must be added to these longitudes in order to obtain those of PZT #3.

In the establishment of the 1968 B.I.H. System (68BIHS, B.I.H.=Bureau Internationale de l'Heure) the longitude of the 'Washington PZT' is defined to be $15^s.7374$ [3]. This value is a part of the definition of the 68BIHS, and any changes in longitude are absorbed by analytical corrections applied to the Washington observations by the B.I.H. in order to refer them to the 68BIHS. The 68BIHS value of the 'Washington PZT' longitude erroneously implies that it is the longitude of the physical location of the PZT, while it actually refers to the center of the clock house. The longitude $15^s.7494$ (above) presently used as the 'conventional' or 'effective' longitude of PZT #3 is obtained from the 68BIHS definition by adding to the latter the correction, $+0^s.0120$, in order to refer the star catalog to the FK4 system (See Appendix A).

In 1897-98 a revised value of the latitude of the new observatory was found by G. A. Hill using the prime vertical transit [4]. His value, $13''.97$, rounded to $14''.0$ has been used in the *AE* since 1901. Footnotes in the *AE* beginning with the 1957 edition have been confusing. Whereas the printed coordinates have continued to refer to the center of the clock house, the footnotes have mentioned either the 'equatorial refractor' or the 'zenith telescope', located elsewhere on the grounds. No instrument has ever been located at the clock house.

The latitude adopted for the physical location of PZT #3 has been published as $38^\circ \ 55' \ 17''.03$, which value is based upon observations using the original star catalog. In the establishment of the 68BIHS the latitude of the instrument was defined to be $16''.860$, referred to a fixed reference pole position called the Conventional International Origin (CIO), formerly the Mean Pole of 1903. With the introduction of a catalog on the FK4 system the latitude has been redetermined to be $17''.243$ (See Appendix A).

It should be noted that in general the determination of astronomical latitude can depend upon the catalog positions of the stars observed, refraction, flexure and/or other instrumental characteristics which depend in turn upon the particular instrument, and upon the variation of latitude. Observing methods are devised to minimize the errors from these sources. The effect of variation of latitude on determinations made by instruments other than PZT's is usually eliminated to a large extent by applying corrections determined from observations made by a PZT, or by using published coordinates of the pole from the B.I.H. or from the International Polar Motion Service (IPMS), formerly the International Latitude Service (ILS).

The U.S. Naval Observatory Time Service Substation (NOTSS), located in Richmond, Florida, began observations with a PZT on 4 November 1949. Its position, based on its own early observations, was published as follows:

$$\lambda = 5^h\ 21^m\ 31^s\!.3 \text{ W}$$
$$\phi = 25^\circ\ 37'\ 28'' \text{ N}$$

The Richmond instrument (PZT #2) was moved and installed in its present position in 1954, and observations from the new position commenced 15 November 1954. Longitudes of PZT #2 at its present site which have been used in the past are:

	s
15 November 1954 to 31 December 1960	31.759
1 January 1961 to 31 December 1961	31.730
1 January 1962 to 31 December 1968	31.719
1 January 1969 to 31 December 1971	31.7050
1 January 1972 to present	31.7030

In the establishment of the 68BIHS the longitude of the Richmond PZT was defined to be $5^h\ 21^m\ 31^s\!.7270$. Again, as in the case of the Washington PZT, this value is a part of the definition of the system, and any changes in longitude are absorbed by analytical corrections applied by the B.I.H. to the Richmond observations in order to refer them to the 68BIHS. The longitude presently used for PZT #2 is obtained from this B.I.H. definition by adding to it the correction, $-0^s\!.0240$, in order to refer the star catalog to the FK4 system. (See Appendix A).

The latitude adopted for PZT #2 at its present location, based upon observations using the original star catalog, has been published as $25^\circ\ 36'\ 47''\!.13$. In the establishment of the 68BIHS the latitude of the instrument was defined to be $46''\!.927$, referred to the CIO. With the introduction of the catalog on the FK4 system the latitude has been redetermined to be $47''\!.157$ (See Appendix A).

II. Description of Coordinate Systems

This *Circular* contains astronomical and geodetic coordinates. The latter are referred to the 1927 North American Datum (1927 NAD), and to an Earth-centered world geodetic datum, defined in Appendix C. A brief discussion of these different types of coordinate systems follows [5, 6, 7]. Figure 1 illustrates some of the general concepts involved. (N.B. We would like to gratefully acknowledge the guidance and contributions of Mrs. Irene Fischer in the preparation of this section, as well as Appendices B and C.)

Astronomical coordinates are referred to the local astronomical vertical, i.e., the direction in which a plumb line points. These coordinates are determined with respect to the equipotential surface of the Earth's gravitational field (as modified by rotational accelerations) at the point of observation. The direction of local gravity is perpendicular to this equipotential surface, and the horizontal axis of an astronomical instrument that has been leveled with a spirit level or mercury surface is parallel to it.

Astronomical observations of position are perforce made with respect to the instantaneous pole, and hence when variations of the order of ten meters are considered important, an epoch must be associated with astronomical coordinates in order to indicate the pole of rotation to which they are referred. Alternatively they may be referred to the CIO.

The particular equipotential surface which coincides with mean sea level* (MSL) in the open ocean is singled out for special significance in geodesy, and is called the *geoid.* For land areas the geoid may be visualized as the level surface which would be assumed by water in an imaginary network of frictionless channels connected to the ocean. The geoid departs from an ellipsoidal form by amounts of 100 or so meters, at inclinations of as much as a minute of arc. This is because of the irregularities in the shape and density of the Earth. These *undulations* of the geoid should not be confused with the actual surface of the Earth, such as mountains, valleys, and so on. To be precise, astronomical coordinates of a place which is some distance above the geoid differ from what they would be on the geoid, since equipotential surfaces are not, in general, parallel. This relatively small correction, which involves either assumptions about the homogeneity of the Earth, or a more detailed calculation of local densities, is not usually applied.

Geodetic coordinates are referred to an oblate ellipsoid of revolution whose size and shape are chosen to closely approximate the geoid either 'locally' (say over a continent), or globally over the entire Earth. (The terms 'ellipsoid' and 'spheroid' are often used interchangeably in geodesy, although strictly speaking, the first is a mathematically well-defined surface, while the latter is a general term for any roughly sphere-like surface.) The ellipsoid may be defined by the lengths of the equatorial and polar radii, a and b respectively, or by the length of the equatorial radius plus a parameter which indicates the departure from a sphere. Such a parameter may be either the flattening, $f = (a - b) / a$, or the eccentricity, $e = (a^2 - b^2)^{1/2} / a$.

In 1967 the International Union of Geodesy and Geophysics (IUGG) recommended that the minor axis of the reference ellipsoid be parallel to the direction defined by the CIO [8]. In this case then, geodetic coordinates do not require an associated epoch.

Geodetic coordinates necessarily depend upon measurements made upon the Earth's surface, but the coordinates are computed and adjusted on the chosen reference ellipsoid. There are many systems of geodetic coordinates in use throughout the world. Each system is referred to a particular geodetic datum, defined by the coordinates of an arbitrarily selected initial point, the ellipsoid used, and the azimuth of a reference line. The coordinates of the initial point are often, but not always, taken from the astronomical coordinate system. Subsequent points are connected by triangulation or traverse, and heights are determined by leveling. The measures are projected onto the reference ellipsoid and converted into longitudes and latitudes in an adjustment process. In general, the center of the reference ellipsoid will not coincide with the Earth's center of mass, nor will its size and shape necessarily be appropriate for the Earth as a whole. The reference ellipsoid is primarily a regular surface used to facilitate the computations.

Heights are usually measured from MSL (the geoid). These heights must be corrected for the undulations mentioned previously in order to arrive at the height above the ellipsoid. Thus, if H is the height of some particular location above the reference ellipsoid, and h is its height above MSL, then $H = h + N$, where N is the height of the geoid above the reference ellipsoid at the location, and includes the local undulation. It is necessary to know the value of H if one wishes to have the correct coordinates for global problems.

The difference between astronomical and geodetic coordinates for the same spot on the surface of the Earth is a measure of the 'deflection of the vertical'. These deflections may occasionally be as large as a minute of arc; deflections as large as 10 seconds of arc are not unusual. The deflections may be due to both the arbitrary definition of the ellipsoid, and to the actual form of the geoid brought about by the Earth's irregularity of form and density. Measurements of the deflections of the vertical over extensive areas have been used as a method for determining the undulations of the geoid.

*Mean Sea Level (MSL) has been used in the present work as the basis for the elevations of stations. These elevations are, to be more precise, referred to the Sea-Level Datum of 1929. a uniform hypothetical surface which approximates the level of the ocean for inland points, and which avoids problems such as the 'slope' of the ocean surfaces as determined by leveling along coastlines. For further discussion of this matter, see [36].

It should be noted that astronomical coordinates are a pure *orientation* system, consisting of latitude and longitude only. (Recently it has become common in geodesy to introduce the height above MSL as a third 'astronomical' coordinate.) In principle, a point on the surface of the earth which is west or north of another point geographically, could be east or south of it in astronomical coordinates and vice versa.

On the other hand, geodetic coordinates are a *location* system, in which three coordinates must be specified. These coordinates have a one-to-one correspondence with geographical locations. The customary third coordinate in geodesy is the height above the reference ellipsoid, the quantity H mentioned previously. The quantity most often available from geodetic maps is the height above MSL, h, and hence a knowledge of the quantity N is required. Maps from which the values of N may be obtained are becoming widely available [9].

Ideally the center of the reference ellipsoid should coincide with the center of mass of the Earth. Until very recently no method of ensuring this correspondence was available. Gravimetry and satellite geodesy, often in conjunction with classical geodetic techniques (such as finding the deflections of the vertical; see above) are now being used, and 'world' (Earth-centered) geodetic datums are now available.

Coordinates are given in this *Circular* in one such world datum using the ellipsoid based on the Geodetic Reference System 1967 (adopted by the International Association of Geodesy in 1971) [10]. This is essentially equivalent to the 1964 IAU system [11]. Alternative center-of-mass coordinates appear in Appendices D and E. General formulas for transforming coordinates from one geodetic datum to any other are given in Appendix B.

The *geodetic* latitude, ϕ, is the angle between the normal to the ellipsoid at the point of observation and the equator. A quantity called the *geocentric* latitude, ϕ', defined as the angle between the radius vector and the equator, is often needed in astronomical applications. The relationship between the geodetic and geocentric latitudes (which may differ by some 11 minutes of arc at mid-latitudes) may be found from the geometric properties of a meridian section of the ellipsoid. The expression,

$$\tan \phi' = (1 - e^2) \tan \phi,$$

gives the geocentric latitude in terms of the geodetic latitude. Other relationships may be derived. These include expressions for the difference, $(\phi' - \phi)$, in terms of sines of multiples of the latitude, and tables (in the *AE*, for example) which give the values of S and C in the formulas:

$$\rho \sin \phi' = (S + H) \sin \phi,$$
$$\rho \cos \phi' = (C + H) \cos \phi,$$

where ρ is the magnitude of the radius vector, and H is the height above the reference ellipsoid, both in units of Earth radii.

Geocentric longitudes are the same as geodetic longitudes in a world geodetic system. In astronomical applications requiring a precision of more than about four significant digits in the observer's geocentric coordinates, only world geodetic coordinates should be used in the above formulas.

The appropriate coordinates to be associated with an astronomical telescope depend upon its use. Transit circles and zenith telescopes are usually concerned only with their astronomical coordinates (orientations). However, when observations are made of nearby objects (e.g. the Moon, artificial satellites, etc.), the parallax corrections should be computed using world geodetic coordinates. For more distant objects in the solar system even the maximum deflections of the vertical lead to negligible errors in reducing the observed position of an object to its position as seen from the center of mass of the Earth. The error caused by using astronomical coordinates or geodetic coordinates which are not referred to the center of mass is of the order of $d / R = d / (23456\, r)$, where d is the deflection of the vertical, R is the distance to the object in earth radii, and r is the distance in astronomical units.

The astronomical and geodetic meridians of a place do not, in general, coincide and this fact should be taken into account when reducing astronomical observations which depend upon an object's hour angle.

III. Coordinates

This section contains coordinates for the new and old NAVOBSY, Washington, D.C.; for NOTSS, Richmond, Florida; for the Flagstaff Station, Arizona; and for the Southern Transit Circle Division installation at El Leoncito, Argentina. Not all types of coordinates are available for all these locations, but neither are all types required, due to the varied and specialized nature of their observing programs.

The format, which is the same for each of the above locations, is as follows: Coordinates are given explicitly for some selected station at each location. Following this there is a table of differential corrections which permits the calculation of the coordinates for the remaining stations at the location. That is, the numbers found in a table are to be added to the quantities given for the selected station in order to derive the corresponding quantities for the stations listed in the tables. For example, the 1927 NAD latitude of PZT #3 (new NAVOBSY) is found to be 38° 55′ 19″.755. Following each table there appears a list of Station Descriptions which contain historical information and identification aids.

All astronomical latitudes given are referred to the CIO.

Coordinates labeled simply '1967 World' are understood to refer to the world datum more fully described in Appendix C. Appendix F gives additional information concerning the standard antennas used in Washington and Richmond for time signal monitoring. Appendix H has maps of some of the locations.

Measures of precision are not available for the quantities which follow; however it should be assumed that the uncertainties may amount to several units of the last decimal place given in the tables.

A. NAVOBSY, Washington, D.C. (new)

The coordinates adopted for the bronze plaque at the center of the grounds (clock house) are:

	Longitude		Latitude
	h m s	° ′ ″	° ′ ″
Astronomical	5 08 15.7494	(77 03 56.241) W	38 55 14.183 N [1]
1927 NAD	16.1599	04 02.399	16.695 [2]
1967 World	16.119	04 01.78	16.76 [3]

Height above:	
Mean Sea Level	+86.451 m. [4]
Clarke Spheroid (1927 NAD)	+87.6 [5]
1967 World Ellipsoid	+42. [3]

[1] Offset from PZT #3 / FK4; Appendix A.
[2] USC&GS [12]. [3] Appendix C.
[4] Leveled from Bench Mark D. [5] Fischer et al. [9].

STATION	Δ Long.		Δ Lat.	Δ Height
	s	″	″	
NAVAL (Bldg. 1)	−0.2594	−3.891	−1.667	+ 8.13 m.
8-inch Moon Camera (Bldg. 1)	−0.2332	−3.498	−1.697	+12.55
26-inch Refractor (Bldg. 2)	0.0000	0.000	−1.697	+ 5.79
PZT #3 (Bldg. 69)	−0.0400	−0.600	+3.060	− 2.20
PZT #1 (Bldg. 40)	+0.1199	+1.799	+3.060	+ 1.79
65-cm. PZT	+0.1058	+1.588	+2.674	+ 5.35
Astrolabe (Bldg. 10)	+0.1330	+1.995	+2.670	+ 2.00
6-inch Transit Circle (Bldg. 7)	+0.0692	+1.038	+0.074	+ 1.64
Automatic Transit Circle (Bldg. 6)	−0.0692	−1.038	+0.074	+ 2.46
24-inch Reflector (Bldg. 39)	+0.187	+2.81	+2.38	+ 6.79
15-inch Astrograph (Bldg. 38)	0.000	0.00	+3.96	− 1.15
8-inch Twin Astrograph (Bldg. 87)	+0.041	+0.62	+2.94	− 0.47
5-inch Refractor (Bldg. 78)	−0.182	−2.73	−3.40	+ 2.22
5-inch NCA Refractor (Bldg. 25)	−0.088	−1.32	−3.51	− 4.12
Photoheliograph (Bldg. 78)	−0.197	−2.96	−3.10	+ 2.01
South Transit (Bldg. 8)	−0.1901	−2.852	−1.696	
Prime Vertical Transit	0.0000	0.000	+0.518	
Washington Standard Antenna (Bldg. 78)	−0.182	−2.73	−3.40	+ 0.26
Bench Mark A				+ 0.327
Bench Mark B				− 0.648
Bench Mark C				+ 0.103
Bench Mark D				− 1.048
Bench Mark E				− 4.461

STATION DESCRIPTIONS

NAVAL. USC&GS triangulation station (third order) located on the roof of the main building (Bldg.1); USC&GS description (1912):"To reach station go up winding stairway near W end of building to the top, thence eastward through a door and down three steps to the stone walk along top of building. Station is 1.670 meters E of the face of the wall where you have just come out and 0.825 meters from N iron rail, 1.895 meters from S iron rail along walk. The N edge of the stone walk is 1.14 meters distant from station and S edge 2.22 meters distant. The bottom step, where you have just come out, is 0.76 meter from station. A small hole in center of a shallow cross marks center of station, cut in the stone floor (slate)." [13]. USC&GS recovery note (1940):"Station not recovered. Cross-mark was not searched for because the roof was covered over with a tar roofing composition, and a board walk built over this, but the walls and steps referenced to the station in the original description are unchanged and the station can be recovered from these." [13]. Except for the board walk, which has been removed, this information is current as of February 1974.

8-inch Moon Camera. The center of the dome housing this instrument is also a USC&GS triangulation station (1894; recovered 1940), designated as "*NEW NAVAL OBSERVATORY, CENTER OF SMALL DOME ON MAIN BUILDING*" by the USC&GS [13]. The dome housed the 12-inch equatorial telescope from 1895 to 1957, the 8-inch equatorial since 1957. The Time Service Moon Camera has been attached to the 8-inch since its installation. Height refers to intersection of axes of mounting.

26-inch Refractor. Alvan Clarke equatorial telescope, mounted on its present pier and mounting since 1893. At the old NAVOBSY from 1873 until 1893 using a different mounting. Height refers to intersection of axes of mounting.

PZT #3. In use at this site since April 1956. Previously located in Bldg.10 (1954–1956). Height refers to the plateholder.

PZT #1. This site occupied by PZT #1 from 1915 to 1955, and has been unoccupied since 1955. Height refers to the plateholder.

65-cm PZT. The installation of the instrument at this site began during 1974. Height refers to the plateholder.

Astrolabe. Original astrolabe installed at this site 1959; in use 1959 to 1961, then removed to Richmond Florida. New astrolabe installed 1970. This site occupied by PZT #3 from May 1954 to April 1956, and previously by the altazimuth telescope from 1893 to about 1934. Height refers to astrolabe prism.

6-inch Transit Circle. Instrument in use at this site since 1899. Height of axis is given.

Automatic Transit Circle. Building first occupied by 9-inch Transit Circle until 1945; 7-inch Transit Circle from 1955 to 1967; Automatic Transit Circle beginning 1972. Height refers to axis of instrument.

24-inch Reflector. Installed 1971. This dome housed the 40-inch reflector (now in Flagstaff) 1935 to 1954; the 12-inch equatorial from 1957 to 1971. Dome built in 1932; rotating portion replaced 1971. Height refers to intersection of axes of mounting.

15-inch Astrograph. Mounting installed 1934. A 10-inch lens used 1942 to 1950. Present 15-inch lens installed 1950. Dome built 1932. Height refers to intersection of axes.

8-inch Twin Astrograph. Two telescopes sharing a common mounting. Installed together with dome in 1971. Height refers to intersection of axes.

5-inch Refractor. Clarke refractor on roof of Simon Newcomb Laboratory (Bldg.78), dome installed 1962. Dome originally used for USAF Satellite Camera No.659, 1963 to 1965. Five-inch installed 1966, and is one of the original 'transit-of-Venus' telescopes. Height refers to intersection of axes.

5-inch NCA Refractor. Clarke refractor, at this site since about 1939; property of National Capital Astronomers, Inc. (organization of amateur astronomers). This area previously occupied by the 'meridian instrument of 40-foot photoheliograph' beginning about 1894. Height refers to intersection of axes.

Photoheliograph. This instrument, most recently located on the roof of Bldg.78, was the only remaining one of eight identical instruments purchased from Alvan Clarke in 1874 for use in the transit-of-Venus work of that year. The instrument is identified as 'Objective No.2' and 'Heliostat No.5'. It was used at Hobart, Tasmania in 1874, and in Washington at the old NAVOBSY for the transit of 1882. At the old NAVOBSY it was installed on a meridian to the east of the 26-inch telescope. At the new NAVOBSY it was originally installed to the west of the site of the Simon Newcomb Laboratory(SNL), moved to a site about 20 feet south of the south transit building, and finally installed on the roof of SNL. Observations with this instrument were discontinued as of 1 January 1972, and the instrument has been dismantled. Height refers to the center of the objective lens.

South Transit. In use at this site from about 1894 until 1904 as a time-determining instrument. This is the 5.3-inch telescope previously used at the old NAVOBSY. It was finally removed from service about 1940 after having been used for experimental work in conjunction with improvements made to the six-inch transit circle. No height is available.

Prime Vertical Transit. In use at this site from about 1894 to 1925. Building, which was located just to the north of the clock house, was razed about 1935. Previously used at the old NAVOBSY from 1845 until relocated at the new NAVOBSY. No height is available.

Washington Standard Antenna. Site designated as reference location of antennas used in time signal monitoring (See Appendix F).

Bench Mark A. This bench mark (BM) as well as bench marks B through F below are USC&GS bench marks laid out in 1927; chief of party was H.S.Rappleye. Description: The center of a horizontal brass plate surmounting a pedestal of brass tubing, projecting vertically from the center of a circular radiator in the center of the clock house [14]. Height above MSL; 87.427 meters = 286.83 feet. Present status: Apparently the brass tubing and the radiator were removed very shortly after the USC&GS party had completed its survey, and a brass plaque was then installed at floor level. This is the plaque in the clock house today. The floor level height is given as 283.63 feet (see description of plaque at the end of this group of Station Descriptions), from which it would appear that the brass tubing was about 3.20 feet long.

Bench Mark B. Description: A + cut with a chisel in the center of the west edge of the nearest concrete pier northeast of the center of the clock house [14]. Height above MSL; 86.452 meters = 283.63 feet [14]. Present status: This BM is probably still intact, but it is covered by asbestos tile and storage bins at the present time. Note that it has the same height as the brass plaque which is countersunk into the aforementioned tile.

Bench Mark C. Description: A – cut with a chisel in the barometer pier of the (at the time) 9-inch transit house. About 2½ feet above floor level [14]. Height above MSL; 87.203 meters = 286.10 feet. Present status: Removed during the installation of the 7-inch transit circle (about 1956).

Bench Mark D. Description: A chiseled square located in the center of the east end of the door sill at the entrance to the 26-inch equatorial house [14]. Height above MSL; 85.403 meters = 280.19 feet. Present status: Intact. Height verified differentially with BM E, below.

Bench Mark E. Description: A chiseled square located in the NW corner of the top step at the south entrance to the main building (Bldg.1). (Additional note: The height of the floor of the main building near the barometer pier was found to be 82.154 meters = 269.53 feet [14].) Height of BM on south top step above MSL; 81.990 meters = 269.00 feet. Present status: BM on the south top step is intact, and was used as a base point for leveling carried out by the committee. As remarked under 'Bench Mark D' above, the height appears to be differentially consistent with bench mark D. Exactly what area of the floor of the main building is alluded to in the additional note is not clear since the barometer was removed some time ago.

Bench Mark F. No description provided by leveling party. Notes found in original book of field observations identify the bench mark only as "Valve Head, located in center of clock house" [15]. Height above MSL; 86.635 meters. Apparently this BM was on a valve of the radiator described under 'Bench Mark A' above, and almost directly under the elevated brass plate.

Remarks concerning the plaque at the center of the grounds. The inscription engraved into this brass plate reads as follows:

LATITUDE = 38° 55′ 14″.0 LONGITUDE = 5 hrs. 8 min. 15.78 sec. WEST
ABOVE SEA LEVEL 283.63 FT.
ZERO MARK
U.S. NAVAL OBSERVATORY
CAPT. EDWIN T. POLLOCK U.S. NAVY
SUPERINTENDENT
Erected 10 February 1927
Position determined 1893–1897–1927

The position given is probably composed of the USC&GS longitude of 1897, Hill's 1897-98 latitude, and the USC&GS height from the then just completed survey. Since its installation in 1927 this plaque has been disturbed; however, whether by accident or design, its position in both longitude and latitude as well as its height appear to be essentially unchanged. Its longitude and latitude were checked by measuring its symmetry with respect to the two transit circles in buildings 6 and 7, its height by a level line from bench mark D. It is presently screwed to a sub-flooring. Although designated as a USC&GS triangulation station, this site was never directly occupied. Instead, a scaffold was erected over the partially constructed building, at its center, and sights were made from there. A plumb line was apparently dropped from the scaffold position, and where it intersected the floor became the center of the grounds. It should be noted that for operational purposes the exact position of this plaque is of little consequence, but for historical reasons (see Appendix G) it is desirable to preserve it.

Remarks concerning physical measurements made at Washington during the course of the present work. Surveying measurements were made by the committee in order to check some existing information and to fill in missing items. All heights given (excepting the reference bench marks) resulted from these measures. Horizontal coordinates given to exactly three decimals of time in the longitude also came from these measures.

B. NAVOBSY, Washington, D.C. (old)

The coordinates adopted for the center of the 'old dome' are:

	Longitude		Latitude	
	h m s	° ′ ″	° ′ ″	
Astronomical	5 08 12.12	(77 03 01.8) W	38 53 39.0	N [1]
1927 NAD	12.4184	06.276	41.925	[2]
1967 World	12.377	05.66	41.99	[3]

Height of the top of the 'old dome' above:

Mean Sea Level	+45.1 m.	[4]
Clarke Spheroid (1927 NAD)	+46.3	[5]
1967 World Ellipsoid	+ 1.	[3]

[1] Offset from new NAVOBSY; coordinate differences from 1950 *AE*. [2] USC&GS [16]. [3] Appendix C. [4] USC&GS [17]. [5] Fischer et al. [9].

STATION	Δ Long.		Δ Lat.	Δ Height
	s	″	″	
Former Site, Transit Telescope	+0.0346	+0.519	0.000	–14. m.
Latter Site, Transit Telescope	–0.0362	–0.543	0.000	–14.
Former Site, Mural Circle	+0.0270	+0.405	0.000	–14.
Latter Site, Mural Circle	–0.0286	–0.429	0.000	–14.
Former Site, Transit Circle	+0.0324	+0.486	0.000	–13.
Latter Site, Transit Circle	+0.0656	+0.984	0.000	–13.
Prime Vertical Transit	0.0000	0.000	–0.449	–14.
9.6-inch Equatorial Telescope	0.0000	0.000	0.000	– 4.
26-inch Refractor	0.0000	0.000	–1.187	–10.
East Pier	–0.0204	–0.306	+0.057	– 6.0

STATION DESCRIPTIONS

Former Site, Transit Telescope. Occupied by instrument from January 1845 to 2 September 1864. Aperture of telescope, 5.3 inches.

Latter Site, Transit Telescope. This was originally the site of the instrument called simply the 'Meridian Circle', from January 1845 to August 1864. The 5.3-inch Transit (above) was moved to this location on 1 October 1864 and remained until the relocation at the new NAVOBSY in 1893 (See 'South Transit' under Station Descriptions, Section III–A).

Former Site, Mural Circle. Occupied by the instrument from January 1845 to 15 September 1845. Aperture of telescope, 4.0 inches.

Latter Site, Mural Circle. The instrument (above) was moved to this location on 1 October 1845 and remained in place until the move to the new observatory in 1893.

Former Site, Transit Circle. Instrument occupied this site from 1 January 1866 until 5 January 1869. Aperture of telescope, 8.5 inches.

Latter Site, Transit Circle. Instrument (above) moved to this location on 1 October 1869 and remained until the move to the new observatory in 1893.

Prime Vertical Transit. This instrument, of aperture 4.9 inches, occupied this site from January 1845 until its relocation at the new observatory in 1893.

9.6-inch Equatorial Telescope. Located in the center of the old dome from January 1845 until the move to the new NAVOBSY. The top of this dome is also a USC&GS triangulation station, *'NAVAL OBSERVATORY (OLD NAVAL OBSERVATORY DOME, PIPE)'*. An excerpt from the USC&GS station description follows. "Station is at the U.S. Naval Hospital in the NW part of the city. The entrance to the hospital is at East and 24th Streets NW. Station is on top of the dome of the old observatory which is over the entrance to the Medical School. There is a 2-inch pipe on top of the dome which was used as the station." [17] Note: This station was occupied in 1934, and the medical facilities mentioned had replaced the old observatory after the move to the new observatory. The original triangulation station at the old observatory was the 'East Pier' (see below), but this station was not recoverable in 1934.

26-inch Refractor. This instrument was located at the center of the 'new dome' of the old NAVOBSY from 15 November 1873 until its relocation in its present dome at the new NAVOBSY in 1893. A new mounting was installed at the time of the move.

East Pier. Site of a USC&GS triangulation station, '*NAVAL OBSERVATORY (OLD NAVAL OBSERVATORY CHIMNEY)*', occupied in 1863. Excerpt from USC&GS station description follows. "The station occupied is the East Pier, formerly a chimney but afterwards converted into a support for a comet seeker by placing a large circular brown stone slab on top, the center of which is the triangle." [17] Note: This station and the 'old dome' (above) are both referred to as '*NAVAL OBSERVATORY*' in the USC&GS *Descriptions of Triangulation Stations* [17], but are distinguished in the *Geographic Positions* as, '*OLD NAVAL OBSERVATORY CHIMNEY*' [18] and '*OLD NAVAL OBSERVATORY DOME, PIPE*' [16].

Remarks concerning the heights listed above. There is evidently no bench mark on the grounds of the old NAVOBSY. The height of the 'old dome' above MSL was derived from information given in 1863 in a letter by J.M. Gillies, quoted in reference [17]. The differential heights are the results of scalings done from drawings of the buildings at the old NAVOBSY. Supplementary information was obtained from photographs as available. In the cases of the various transits and circles the heights approximate the various horizontal axes; for the equatorial instruments, the intersection of the axes of the mountings.

C. NOTSS, Richmond, Florida

The coordinates adopted for the present site of PZT #2 are:

	Longitude		Latitude	
	h m s	° ′ ″	° ′ ″	
Astronomical	5 21 31.7030	(80 22 55.545) W	25 36 47.157 N	[1]
1927 NAD	32.2541	23 03.812	48.794	[2]
1967 World	32.239	23 03.58	50.21	[3]

Height of the top of the objective lens of PZT #2 above:

Mean Sea Level	+ 7.362 m.	[4]
Clarke Spheroid (1927 NAD)	+22.7	[5]
1967 World Ellipsoid	−28.	[3]

[1] PZT #2 / FK4; Appendix A.

[2] USC&GS [19]. [3] Appendix C.

[4] USC&GS [20]. [5] Fischer et al. [9].

STATION	Δ Long.		Δ Lat.	Δ Height
	s	″	″	
Astrolabe (Bldg. 11) (NOTSS No. 2)	−0.0004	−0.006	+ 0.490	− 1.693 m.
Satellite Camera House (Bldg. 10) (NOTSS 1)	−0.0473	−0.710	+ 0.487	− 3.027
Former Site PZT #2 (outside of compound)	−0.3946	−5.919	+40.789	− 4.
Richmond Standard Antenna (TIMER)	−0.0228	−0.342	+ 0.459	− 3.192
TIMER RM 1	−0.1064	−1.595	− 0.775	− 3.097
TIMER RM 2	+0.0542	+0.813	− 0.579	− 3.138

STATION DESCRIPTIONS

Present Site PZT #2. Observations were begun at this site in November 1954. The center of a small bolt in the center of the objective lens cover is a first order USC&GS traverse station designated as *NOTSS NO 3* [19]. This station was occupied in 1962. In 1954 the center of the mercury basin pier was designated as the third order USC&GS station '*CENTER OF MERCURY BASIN PIER, NEW (PZT), 1954*', [21]. The geodetic position given above for PZT #2 refers to *NOTSS NO 3*. The coordinates of the third-order station with respect to the first-order station are: $\Delta\lambda = -0^{s}.0010$ $(-0''.015)$ and $\Delta\phi = +0''.003$; this reflects the expected inaccuracy of the third-order traverse to this site.

Astrolabe. Instrument installed here prior to January 1965, at which time observations with it were commenced. A USC&GS marker is installed near the center of the floor of this building and is designated as *NOTSS NO2* (first-order triangulation station and bench mark) [22]. The height given refers to the astrolabe prism. The bench mark is 4.545 meters above MSL [25].

Satellite Camera House. A ballistic camera was installed here in early 1962. The observing program was completed in March 1964, and the satellite camera was removed. The building has since been used to house a small telescope and is presently used to house an experimental astrolabe. Building floor contains a USC&GS marker designated as *NOTSS NO1* [22] (first-order station). The height given above refers to this marker, which is also a first-order bench mark [25].

Former Site PZT #2. Location of historical interest only. Located outside the present compound. Instrument was installed and observations begun in October 1949. Removed in 1954. In that year the center of the mercury basin pier was designated as the third-order USC&GS station '*CENTER OF MERCURY BASIN PIER, OLD (PZT) 1954*', and the coordinates given are based upon this position [21]. Height given is ground level.

Richmond Standard Antenna (TIMER). This site, designated as the reference location of the antennas used in time signal monitoring (see Appendix F), physically corresponds to a first-order USC&GS triangulation station located between buildings 10 and 11. Excerpt from USC&GS station description follows: "Station mark is a standard station mark disc, stamped TIMER 1962, set in the top of a square concrete monument which is 2 inches below the surface of the ground. A sub-surface disc was set about 3 feet below the surface of the ground and the disc is stamped TIMER 1962. Mark is 17 feet south of an east-west hurricane fenceline, 110 feet north of the northeast corner of the observatory communications building, 25.2 feet east of the doorway of a 12 x 12 (feet) building and 27.8 feet west of the doorway of a 12 x 12 (feet) building." [23]. The height given refers to the station marker which is also a first-order bench mark [25].

TIMER RM 1. A reference mark (identified by a standard disc stamped TIMER NO 1 1962) 51.627 meters southeast of TIMER, outside the fence which encloses the NOTSS buildings (main [communications] building and the first three stations above). It is ". . . 87 feet northwest of the northwest one of two antenna poles, 55.5 feet east of the north-south fence line, and set in the top of a concrete post about 0.1 feet underground." [25]. The horizontal survey apparently did not make a determination of coordinates (those given were calculated by the committee), but a first-order bench mark was established for the elevation of the marker disc.

TIMER RM 2. Additional station marked by a standard traverse disc laid out by a first-order traverse from TIMER (above). It lies 45.3761 meters southwest of TIMER and ". . . it is covered by a small building that can be removed very easily." [24]. Height given refers to the station marker which is also a first-order bench mark [26].

Remarks concerning the heights listed above. Six National Geodetic Survey bench marks are located at the NAVOBSY Richmond facility. Four of these were included in the leveling done in 1962: TIMER, NOTSS 1, NOTSS 2, and NOTSS 3. Four of the bench marks were on a line leveled in 1966: TIMER, TIMER RM 1, TIMER RM 2, and NOTSS 1; the 1966 values for these four are given in the above table. The local adjustment from the 1962 to the 1966 leveling (+0.012 meters) was determined from the heights of TIMER and NOTSS 1, and this was applied to the 1962 values for NOTSS 2 and NOTSS 3, to derive the values given in the table for these two bench marks. (See also the description of 'Astrolabe', above.)

The height of the Astrolabe prism above the bench mark at floor level (NOTSS NO 2) was measured by NOTSS Richmond personnel.

D. NAVOBSY FLAGSTAFF STATION, Flagstaff, Arizona

The coordinates adopted for the flagpole located near the 61-inch reflector building are:

	Longitude		Latitude
	h m s	° ′ ″	° ′ ″
Astronomical		Not determined	
1927 NAD	7 26 57.62	(111 44 24.3) W	35 11 03.2 N [1]
1967 World	57.81	27.1	03.2 [2]

Height of ground level at the flagpole above:

Mean Sea Level	+2302.0 m. [3]
Clarke Spheroid (1927 NAD)	+2295.3 [4]
1967 World Ellipsoid	+2264. [2]

[1] Scaled from topographic map [27].

[2] Appendix C.

[3] Engineering survey [28].

[4] Fischer et al. [9]

STATION	Δ Long.		Δ Lat.	Δ Height
	s	″	″	
61-inch Reflector	−0.046	− 0.69	−0.72	+13.8 m.
40-inch Ritchey-Chretien	−0.624	− 9.36	+0.37	+10.2
24-inch Reflector	−0.588	− 8.81	+1.29	+11.2
Automatic Transit Circle	+0.871	+13.06	+1.44	−31.5

STATION DESCRIPTIONS

61-inch Reflector. A 152-cm astrometric reflector, dedicated 19 June 1964. The height refers to the intersection of the axes which is 45 feet 6 inches above the ground level adjacent to the dome. The height of the floor of the building is 7553.0 feet above MSL.

40-inch Ritchey-Chrétien. This telescope was originally located at new NAVOBSY in Washington, and was moved to its present location in September 1955. New optics of ULE Fused Silica were installed in 1968. The height given refers to the intersection of the axes which is about 5 feet above the movable floor when the latter is in its unelevated position (which position is at the same height as the general ground level in the vicinity of the building). The building itself is in a three feet deep excavation and the axes lie 8 feet 8½ inches above the bottom of this excavation. The height of the floor in its unelevated position is 7581.0 feet above MSL.

24-inch Reflector. A Cassegrain telescope moved to Flagstaff in 1971. Height refers to the intersection of the axes which lies 8 feet 2½ inches above the ground level. The height of the floor of the building is 7581.0 feet above MSL.

Automatic Transit Circle. Future site of instrument now in Washington (see Station Descriptions, Section III-A). The height given refers to the axis of the instrument which is 17.1 feet above ground level, and 6.1 feet above floor level.

Remarks concerning the heights and differential coordinates listed above. There have been various engineering surveys conducted at Flagstaff in conjunction with the general development of the station. These surveys are listed in chronological order in reference [28]. The floor heights were obtained from the first survey listed; the height of ground level at the flagpole from the second; the differential horizontal coordinates from the third; and the height of the Automatic Transit Circle above the ground and above the floor from the last. For the remaining instruments the heights of the axes' intersections were supplied by Dr. Gerald Kron in a letter dated 16 February 1972.

E. SOUTHERN TRANSIT CIRCLE STATION, El Leoncito, Provincia de San Juan, Argentina

The coordinates adopted for the 7-inch Transit Circle (which was associated with the Yale-Columbia Southern Observatory from 1967 until July 1973) are:

	Longitude		Latitude
	h m s	° ′ ″	° ′ ″
Astronomical	4 37 19.6	(69 19 54.0) W	31 48 10.0 S

Geodetic coordinates using a continental datum are not available.

Height of the axis of the 7-inch Transit Circle above:

Mean Sea Level +2296 m. [1]

[1] Topographic map [29].

The principal instrument of the Yale-Columbia Southern Observatory is the 20-inch Twin Astrograph. For this instrument we have [29]:

STATION	Δ Long.		Δ Lat.	Δ Height
	s	″	″	
20-inch Twin Astrograph	+0.431	+6.46	−0.65	− 4 m.

The differential height refers to the intersection of the axes.

Note: The 7-inch Transit Circle was used at this site from 1967 to 1973 in conjunction with the Southern Reference Star (SRS) program [30]. The coordinates given above were determined from almucantar observations of FK4 stars made with a theodolite by J. A. Hughes while installing the 7-inch Transit Circle and were used for preliminary calculations made during the program. After the compilation of the final catalog (now in progress), corrections to these assumed coordinates will be available. It is not expected that these corrections will be as large as $0^s.1$ and 1″ in longitude and latitude respectively.

APPENDIX A

Astronomical Coordinates of PZT #3 (Washington, D.C.) and PZT #2 (Richmond, Florida)

Observations of astronomical latitude have been made continuously at the U.S. Naval Observatory in Washington, D.C. since October 1915 using a Photographic Zenith Tube (PZT). Since the institution of the system of Coordinated Universal Time (UTC) in 1956, the PZT has also been used to observe the quantity $UT0 - UTC$. These quantities can be used to obtain an astronomical position of the instrument with respect to a chosen position of the pole of rotation of the earth, presently the CIO; and an implicit origin of longitude determined by the BIH. Similarily, the observations made in Richmond, Florida can be used to determine the coordinates of that station.

The observations from Washington and Richmond have been reduced using a consistent method and improved catalogs of star positions and proper motions. These catalogs were developed by minimizing the individual residuals of the star observations, and applying statistical corrections to place the catalog positions on the FK4 system [31]. The improved internal proper motions are not necessarily referred to the FK4 system of proper motions.

Position of the Washington PZT

Observations of Washington latitudes made during the period October 1915 through December 1972 were used in the analysis. During this period two different instruments were used, and the method of observation was also changed. From 28 October 1915 to 7 February 1935, six photographs were taken of each star as it passed through the zenith. Since the latter date only four images of each star have been used to determine latitude. From 1 May 1954 to 4 May 1955 PZT #1 and PZT #3 were used together. PZT #1 was then removed from service. On 14 April 1956 PZT #3 was moved to its present location, $0^{s}.1599$ directly east of the position of PZT #1.

During the period from 1 May 1954 to 14 April 1956 PZT #3 was located at the present site of the astrolabe (Bldg. 10), measured to lie at a latitude $0''.39$ south of the parallel on which PZT #1 was located, and on which the permanent site of PZT #3 is situated. The constant difference in latitude, $0''.39$, was applied to all the latitude data obtained from PZT #3 during this period so that all Washington PZT observations are referred to the same parallel. PZT #3 was already in its present position when the UTC system was instituted.

The star list used in the observations has changed as precession has carried stars in and stars out of the field of the instrument. As a result the list of stars observed with the Washington PZT instruments numbers 116, while the observing program contains about 80 stars at any one time. Of all the stars in the Washington catalog, 39% have been observed from the beginning of the program, and 51% have been observed for at least forty years.

It is well known that the rotational pole of the Earth moves with respect to the body of the Earth in a periodic fashion about a mean pole. The principle periodicities of this motion are 1.0 and approximately 1.2 years [32]. This compound motion results in a beat oscillation with a period of about six years. This oscillation is reflected in the observed astronomical latitudes. Hence the latitude of a station referred to the mean pole is determined by calculating the arithmetic means of the latitude over periods of six years.

From the series of observed Washington PZT latitudes, six-year running means were calculated. These data can be represented by the least squares fit:

$$\phi = (38^\circ\ 55'\ 17''.397 \pm 0''.005) + (0''.0028 \pm 0''.0003) \times (t - 1950.0) ,$$

where t is measured in years, and mean errors are given.

The constant contribution to ϕ in the above expression represents the latitude of the station referred to the mean pole of 1950.0. The correction, $-0''.154$, may be added to obtain the latitude of PZT #3 with respect to the CIO, $17''.243$.

By comparing the values of *UT0 – UTC* obtained by a number of stations observing stars referred to the FK4 system and using synchronized clocks, the longitudes of the contributing stations may be adjusted so that each station gives consistent values of the observed quantity. In conjunction with the BIH this method was used in the adoption of the longitude for PZT #3, namely,

$$\lambda_w = 5^h\ 08^m\ 15^s\!.7094\ ,$$

which value was announced via *Time Service Announcement Series 14*, Number 4.1.

Position of the Richmond PZT

Observations of the latitude of the Richmond PZT #2 from November 1949 through December 1972 were used in the analysis. As mentioned earlier, during this time the instrument was located at two different sites. Measured geodetic differences in latitude and longitude between the two sites were applied to the observations obtained prior to 15 November 1954 in order to refer them to the current position of the instrument. The estimated error of this procedure is a few hundreths of a second of arc since the deflection of the vertical should be changing very slowly between the two sites in question. The method of observation has been the same throughout the history of the station, and the star list has remained virtually the same since 1949, with 89% of the original stars still in the observing list for 1970.

Following the same method as was used for the determination of the Washington astronomical coordinates, six-year running means of the observed Richmond PZT latitudes were calculated. These data can be represented by the least squares fit:

$$\phi = (\,25^\circ\ 36'\ 47''\!.307 \pm 0''\!.010\,) + (\,0''\!.0001 \pm 0''\!.0008\,) \times (\,t - 1950.0\,)\ .$$

As with Washington, the constant part of ϕ represents the latitude of the station with respect to the mean pole of 1950.0. The correction, –0″.150, may be added to obtain the latitude of PZT #2 with respect to the CIO, 47″.157.

As was the case for Washington, the longitude of the PZT in Richmond was adopted in conjunction with the BIH. After the improvement of the catalog in 1971 the adopted longitude for the Richmond PZT is,

$$\lambda_w = 5^h\ 21^m\ 31^s\!.7030\ ,$$

which value was announced via *Time Service Announcement Series 14*, Number 9.

The drift represented by the secular terms in latitude can be the reflection of secular motion of the pole, systematic error in the catalog proper motions, physical motion of the station, or any combination of changes in the direction of the vertical. The CIO astronomical latitudes for Washington and Richmond listed in Sections III-A and III-C are for the epoch 1950.0.

APPENDIX B

Conversion of Geodetic Coordinates to Another Datum

In astronomy, geodetic coordinates based upon 'local' datums, such as the 1927 North American Datum, are of limited usefulness when high precision is needed. Geodetic coordinates based upon a world (Earth-centered) datum are necessary in most such applications.

General formulas for converting coordinates from one datum to another are given below. These formulas assume there are no orientation or scale errors associated with either datum. (Very recent satellite data have been used to determine both orientation and scale errors for several major datums; see e.g. reference [35]. No use of these data is made in this *Circular.*) Under these assumptions each datum is completely defined by specifying (X, Y, Z) = the coordinates of its center with respect to the Earth's center of mass; a = the equatorial radius of its reference ellipsoid; and f = the flattening of the reference ellipsoid.

Defining the quantities

λ_e = longitude *measured eastward from Greenwich;*
ϕ = geodetic latitude;
H = height above the reference ellipsoid,
$= h+N$, where h = height above mean sea level, and N = height of the geoid above the ellipsoid;

and given, in the sense new minus old,

$\Delta X, \Delta Y, \Delta Z$ = the components of the center shift between the two datums, ΔZ positive towards the north pole, ΔX and ΔY in the plane of the equator, positive towards $\lambda_e = 0°$ and $\lambda_e = 90°$ respectively;
Δa = the difference between the equatorial radii;
Δf = the difference between the flattenings;

and using the intermediate quantities

$e^2 = 2f - f^2$ (e = eccentricity),
$R = a / (1 - e^2 \sin^2 \phi)^{1/2}$ (R = radius of curvature in prime vertical),
$r = a(1 - e^2) / (1 - e^2 \sin^2 \phi)^{3/2}$ (r = radius of curvature in meridian),
$b/a = 1 - f$ (b = the polar radius);

then the corrections to the geodetic coordinates ($\Delta\lambda_e$, $\Delta\phi$ in radians, and ΔH in the same units as ΔX, ΔY . . . a, b, etc.) are given by the Molodenskiy formulas:

$$\Delta\lambda_e = \frac{-\Delta X \sin \lambda_e + \Delta Y \cos \lambda_e}{(R + H) \cos \phi},$$

$$\Delta\phi = \frac{-\Delta X \cos \lambda_e \sin \phi - \Delta Y \sin \lambda_e \sin \phi + \Delta Z \cos \phi + [R e^2 (\Delta a / a) + \Delta f (a\, r / b + b\, R / a)] \sin \phi \cos \phi}{(r + H)},$$

$$\Delta H = \Delta X \cos \lambda_e \cos \phi + \Delta Y \sin \lambda_e \cos \phi + \Delta Z \sin \phi + (a\, \Delta a / R) + (b\, \Delta f\, R \sin^2 \phi) / a.$$

APPENDIX C

Conversion from 1927 North American Datum to the 1967 World Datum

The 1927 North American Datum (1927 NAD) is based upon the Clarke Spheroid of 1866 which is defined by the parameters $a = 6378206.4$ meters and $b = 6356583.8$ meters. The initial point of this datum is triangulation station MEADES RANCH, Kansas, with the orientation defined by the azimuth to station WALDO.

The Geodetic Reference System 1967 Ellipsoid is a reference ellipsoid defined by the parameters $a = 6378160$ meters and $f = 1 / 298.247167427$ [33].

The displacement of the center of the 1927 NAD from the center of mass of the Earth has been determined by satellite geodesy using the Modified Mercury Datum as an intermediary [34]. Both the 1967 World and Clarke axes of symmetry are assumed to be aligned with the Conventional International Origin (CIO), and to have a common origin of longitude.

The parameters relating the two reference ellipsoids are, in the sense of 1967 World minus 1927 NAD,

$$\Delta a = -46.4 \text{ meters},$$
$$\Delta f = -3.7151591 \times 10^{-5}.$$

The estimated displacement of the center of the 1927 NAD reference ellipsoid from the Earth's center of mass is, in the same sense,

$$\Delta X = -\ 18 \text{ meters},$$
$$\Delta Y = +145 \text{ meters},$$
$$\Delta Z = +183 \text{ meters} \quad [34].$$

For this special case the general formulas of Appendix B can be simplified to the following short forms, accurate to about 2%:

$$\Delta\lambda''_w = \frac{+4.73 \sin(\lambda_w - 82.^\circ 9)}{\cos\phi},$$

$$\Delta\phi'' = (+4.76 \cos(\lambda_w - 82.^\circ 9) - 15.45 \cos\phi) \sin\phi + 5.96 \cos\phi,$$

$$\Delta H_m = -146 \cos(\lambda_w - 82.^\circ 9) \cos\phi + (183 - 237 \sin\phi) \sin\phi + 46,$$

where λ_w is the longitude *west* of Greenwich.

Applying the full precision formulas to the locations of interest here, one obtains:

	$\Delta\lambda_w$		$\Delta\phi$	ΔH
	s	″	″	
Washington, D.C.	−0.0413	−0.619	+0.067	−45.1 meters
Richmond, Florida	−0.0155	−0.232	+1.418	−50.3
Flagstaff, Arizona	+0.1855	+2.782	+0.008	−31.3

APPENDIX D

Alternative Center-of-Mass Coordinates for New NAVOBSY, Washington, D. C.

In 1972 the U.S. Naval Oceanographic Office (NAVOCEANO) kindly offered to determine the center-of-mass coordinates of NAVOBSY by means of satellite tracking using a Geoceiver. The location of the antenna during the ensuing observations has been marked with a disc inscribed "20037". This location is on the roof of Building 1. The following is an excerpt from Enclosure 1 to 'NAVOCEANO ltr ser 4304', a letter from the Commander of the U.S. Naval Oceanographic Office to the Superintendent U.S. Naval Observatory, dated 30 May 1972:

"Following below are satellite-derived positions based on the International Astronomical Union Ellipsoid of 1964 (parameters a=6378160 and f=1/298.25). [Note: This ellipsoid is not significantly different from the Geodetic Reference System 1967 Ellipsoid–see Appendix C.]

Geoceiver Station #20037

Lat.	38° 55′ 15″.26	N
Long.	77° 03′ 57″.27	W

39.59 meters above the ellipsoid

Station NAVAL

Lat.	38° 55′ 15″.28	N
Long.	77° 03′ 58″.26	W

39.59 meters above the ellipsoid

"Following below are satellite-derived positions shifted to North American Datum of 1927 using Molodenskiy's transformation formulas with ΔX=+24, ΔY=–154, and ΔZ=–188. [Note: These center-shift values were derived from NAVOCEANO observations made over the continental United States over the past several years. With the signs reversed they may be compared with the center shift given in Appendix C.]

Geoceiver Station #20037

Lat.	38° 55′ 14″.88	N
Long.	77° 03′ 57″.73	W

89.71 meters above the ellipsoid

Station NAVAL

Lat.	38° 55′ 14″.90	N
Long.	77° 03′ 58″.72	W

89.71 meters above the ellipsoid."

The implication of these observations is that the Washington geodetic coordinates given earlier in this *Circular* should receive small corrections. However, since the survey errors in the 1927 NAD coordinates are comparable in size to the errors of these center-of-mass coordinates (i.e., several meters in each case), it is not clear how any corrections should be apportioned.

APPENDIX E

Alternative Center-of-Mass Coordinates for NOTSS, Richmond, Florida

In 1972 the U.S. Naval Oceanographic Office kindly offered to determine the center-of-mass coordinates of the NOTSS, Richmond, Florida by means of satellite tracking using a Geoceiver. The location of the antenna during the ensuing observations coincided with station TIMER (see Station Descriptions, NOTSS, section III–C), and is also designated by NAVOCEANO as "Geoceiver Station #20038". The following is an excerpt from Enclosure 1 to 'NAVOCEANO ltr ser 4326', a letter from the Commander of the U.S. Naval Oceanographic Office to the Superintendent U.S. Naval Observatory, dated 6 October 1972. Note: The remarks concerning the ellipsoid and center shift which appear in Appendix D apply in precisely the same manner here.

"Results of a NAVOCEANO Geoceiver Survey conducted at the Naval Observatory Time Service Substation, Richmond, Florida between 5 June 1972 and 26 June 1972.

"Following is the satellite-derived position based on the International Astronomical Union Ellipsoid of 1964 (parameters a = 6378160 and f = 1/298.25).

Geoceiver Station #20038 (TIMER)
Lat. 25° 36′ 50″.56 N
Long. 80° 23′ 03″.41 W
−42.16 meters above the ellipsoid

"Following is the satellite-derived position shifted to North American Datum of 1927.

Geoceiver Station #20038 (TIMER)
Lat. 25° 36′ 48″.87 N
Long. 80° 23′ 03″.48 W
15.04 meters above the ellipsoid."

The implication of these observations is that the Richmond geodetic coordinates given earlier in this *Circular* should receive small corrections. However, since the survey errors in the 1927 NAD coordinates are comparable in size to the errors of these center-of-mass coordinates (i.e., several meters in each case), it is not clear how any corrections should be apportioned; except that recent geodetic work along the East Coast of the U.S. seems to indicate the presence of systematic shifts in the 1927 NAD latitudes in southern Florida.

APPENDIX F

Location of Antennas Used in Time Signal Monitoring

Monitoring of radio time signals by the U.S. Naval Observatory requires that the geodetic positions of the receiving antennas be known so that adjustments may be made for the travel times of the radio signals. Although different antennas are used in the monitoring of various signals, a standard antenna location is defined. When there is need for high precision, the internal delays of the monitoring system are adjusted so that all times of reception are published with respect to the standard antenna location.

The coordinates of these standard antennas for Washington, D.C. and Richmond, Florida are listed below. These locations are given in the 1967 World System described in Appendix C.

	Longitude		Latitude	H
	h m s	° ′ ″	° ′ ″	
Washington Standard Antenna	5 08 15.937	(77 03 59.05) W	38 55 13.36 N	+42 meters
Richmond Standard Antenna	5 21 32.216	(80 23 03.24) W	25 36 50.67 N	−31 meters

The physical location of the Washington Standard Antenna is the center of the dome atop the Simon Newcomb Laboratory. (Bldg. 78). The dome is located approximately in the center of an array of antennas on the roof of the building. The height given above refers to the floor of the dome. This dome itself is actually occupied by an astronomical instrument. (See Station Description '5-inch Refractor', Section III-A.)

The physical location of the Richmond Standard Antenna is a USC&GS triangulation station located on the grounds of the Richmond station. (See Station Description 'Richmond Standard Antenna TIMER', Section III-C.)

APPENDIX G

Some Historical Notes

The U.S. Naval Observatory was established 18 August 1842 by an Act of Congress. It was first located in northwest Washington near the intersection of the extensions of E Street and 24th Street. This location is referred to as the 'old' Naval Observatory. During the next half century many observing programs were carried out at this site.

An Act of Congress passed 28 September 1850, provided among other things, "That hereafter the meridian of the observatory at Washington shall be adopted and used as the American meridian for all astronomic purposes and . . . that the meridian of Greenwich shall be adopted for all nautical purposes." This Act was repealed 22 August 1912. While it was in effect, the meridional boundaries of most of the territories and states in the western great plains and Rocky Mountain areas were established an integral number of degrees of longitude from Washington [a]. (See references for this Appendix immediately following it.)

The selection of the Greenwich meridian as the initial meridian for longitude by the International Meridian Conference in 1884, and the adoption of a system of standard time zones referred to Greenwich for the United States and Canada earlier that same year, meant that the Washington meridian was little used [b].

As the city of Washington grew and it became apparent that observations were being hindered by proximity to the city, a decision was made to move to a new location, far enough away that it would be 'a hundred years' before the city again overtook the observatory. The selected location was the present site, four miles from the U.S. Capital!

The *American Ephemeris and Nautical Almanac* has always printed a list of observatories throughout the world. Until the 1916 edition, longitudes were referred both to the meridians of Greenwich and Washington. In the edition for 1899 the origin of longitudes from Washington was changed from the old to the new Naval Observatory, a difference of -3.67 seconds of time. Little notice of the change was given in the text of that edition. The coordinates for both observatories continued to be printed for several years.

It is possible that the longitude of the Lowell Observatory in Flagstaff, Arizona, and that of the Naval Observatory Flagstaff Station (determined differentially from Lowell) were in error due to the change in the longitude of the initial point in Washington near the time of the original determination of the Lowell longitude. In the 1970 edition of the *American Ephemeris* the Lowell and Naval Observatory Flagstaff longitudes were corrected by $5\overset{s}{.}4$ and $4\overset{s}{.}5$ respectively, to the east, reflecting new independent determinations of the positions.

The Naval Observatory has taken part in international cooperative determinations of differential longitudes, including the Paris–Washington program of 1913–14 [c], and the San Diego–Washington programs of 1926 and 1933 [d and e]. The first of these gave the longitude of Washington, using the accepted Paris–Greenwich difference in the link, as

$$5^{h}\ 08^{m}\ 15\overset{s}{.}721 \pm 0\overset{s}{.}014$$

Besides the observing programs which have as their prime purpose the determination of latitude, many of the Washington observation programs are of such a nature that a value of the latitude is found as a by-product. Some of these results are listed below. The values listed have all been corrected to the center of the clock house, but no other corrections have been applied. The various observing programs have applied corrections for the periodic part of the variation of latitude, and the observing schemes are usually set up to eliminate or minimize the effects of errors in the catalog positions of the stars, refraction and the like. No attempt has been made to refer these latitudes to the CIO.

Program	*Latitude* +38° 55′ ″	*Reference*
Weighted mean of observations by W. Harkness and G.A. Hill, 1893–96, and O.B. French (USC&GS) 1897	13.74	[f]
Prime Vertical observations by G.A. Hill, ending 1918:		[g]
2465 observations of 21 stars from Newcomb's catalog	14.031	
3313 observations of 77 stars from Boss' Prelim. Catalog	14.428	
Prime Vertical observations by G.A. Hill, ending 1924:		[h]
3957 observations of 16 stars on 822 nights	14.049	
9-inch Transit Circle observations:		
1903–1913	14.00	[i]
1913–1926	13.84	[i]
1935–1945	13.66	[j]
6-inch Transit Circle observations:		
1909–1910	13.98	[k]
1911–1918	13.66	[k]
1925–1930	13.78	[l]
1925–1941	13.95	[l]
1941–1948	13.92	[m]
1949–1956	14.02	[n]
1956–1962	14.12	[o]

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(b) *Protocols of the Proceedings of the International Conference held at Washington for the Purpose of Fixing a Prime Meridian and a Universal Day*, October 1884.

(c) *Determination of the Difference of Longitude between Washington and Paris, 1913–1914.* Appendix to Publ. of the U.S. Naval Observatory, Second Series, Vol. IX, 1916.

(d) *World Longitude Operation of 1926. Results of Observations at San Diego and Washington.* Publ. of the U.S. Naval Observatory, Vol. XII, Part I, 1929.

(e) *World Longitude Operation of 1933 at San Diego and Washington.* Publ. of the U.S. Naval Observatory, Vol. XIV, Part V, 1938.

(f) *Astron. J.*, June 1897.

(g) *Annual Report of the Naval Observatory for the Fiscal Year 1919*, 1919.

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(i) *Publ. of the U.S. Naval Observatory*, Vol. XII, 1933.

(j) *Publ. of the U.S. Naval Observatory*, Vol. XV, Part V, 1948.

(k) *Publ. of the U.S. Naval Observatory*, Vol. XI, 1927.

(l) *Publ. of the U.S. Naval Observatory*, Vol. XVI, Part I, 1949.

(m) *Publ. of the U.S. Naval Observatory*, Vol. XVI, Part III, 1952.

(n) *Publ. of the U.S. Naval Observatory*, Vol. XIX, Part I, 1964.

(o) *Publ. of the U.S. Naval Observatory*, Vol. XIX, Part II, 1968.

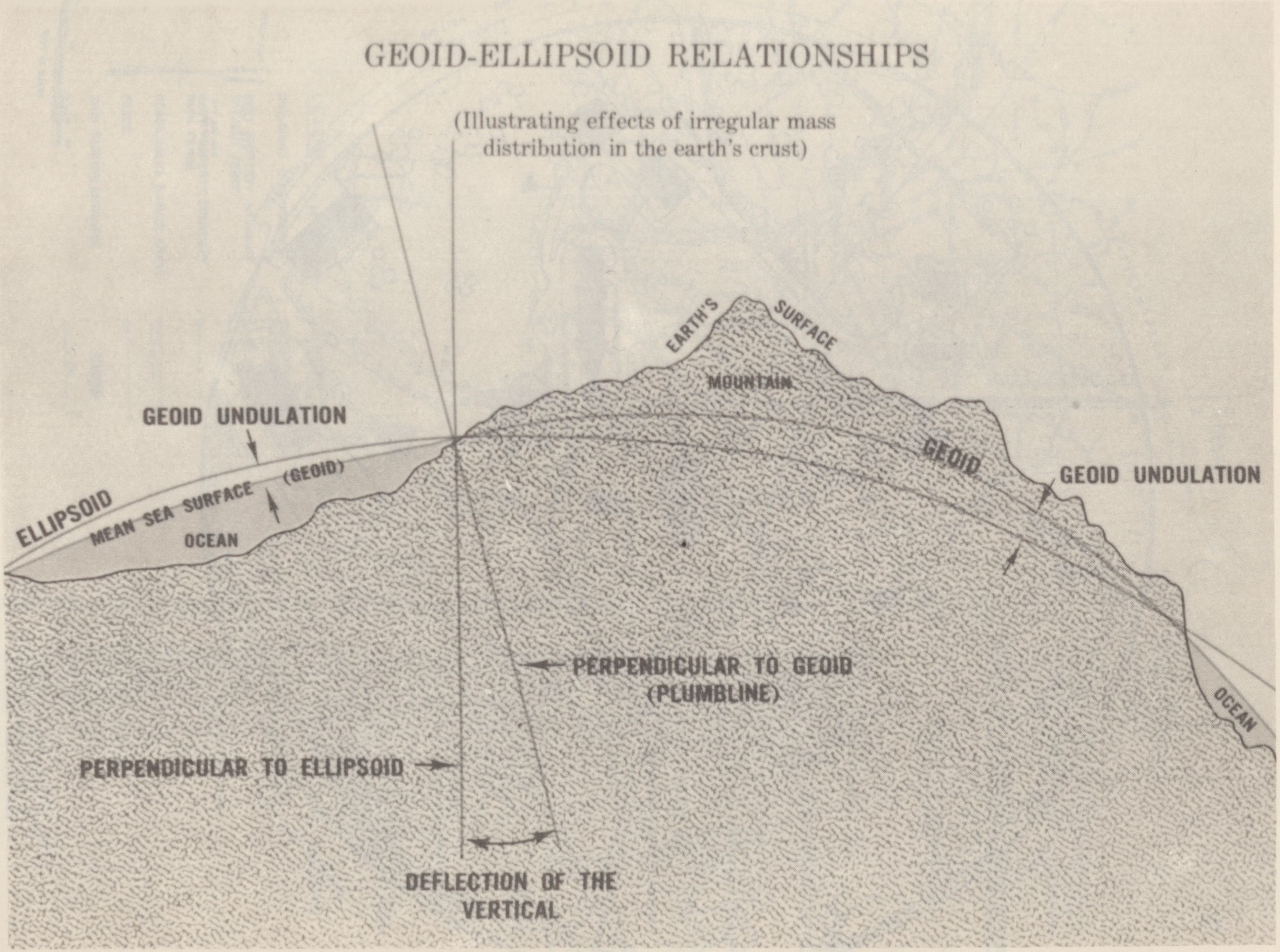
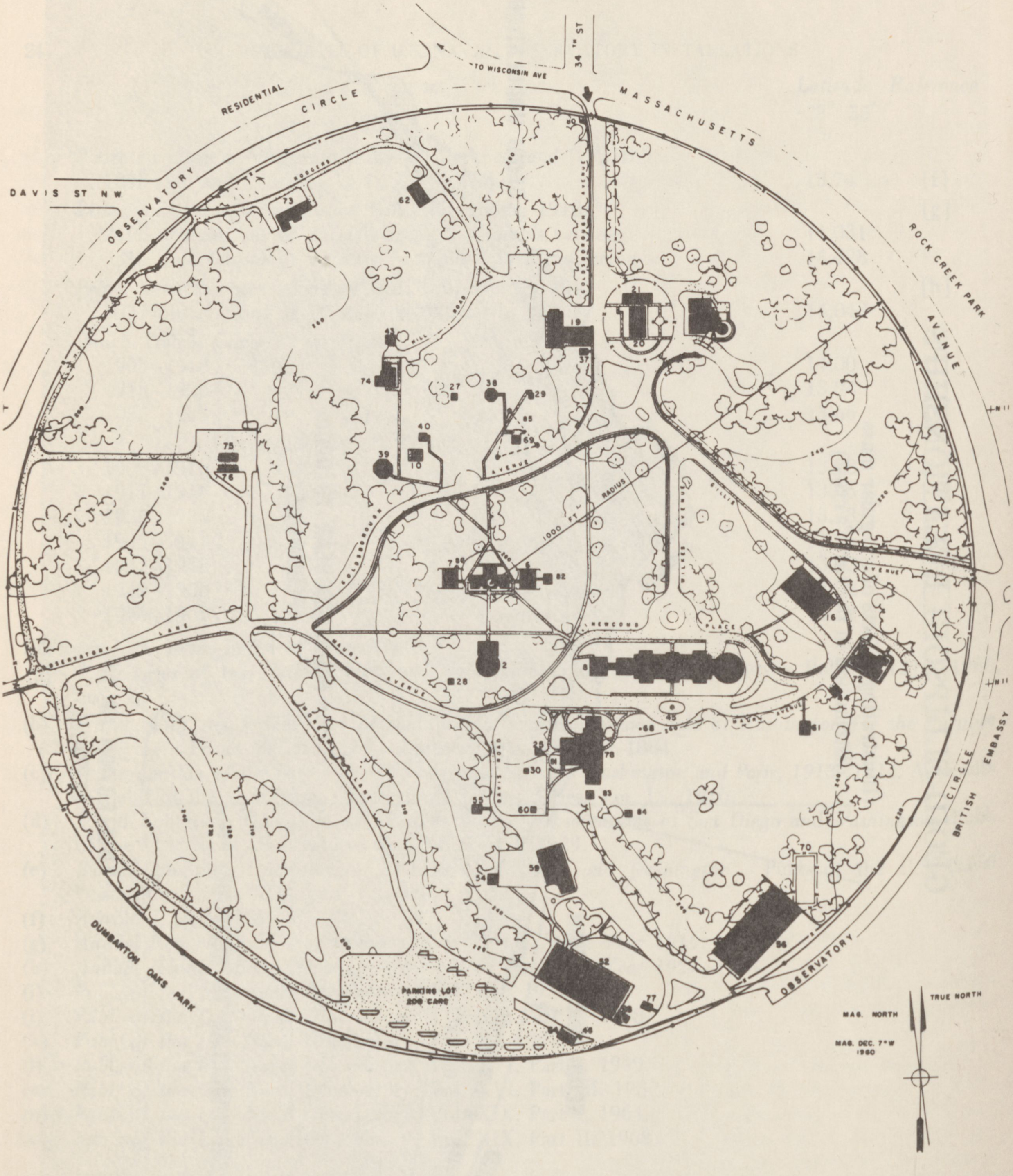
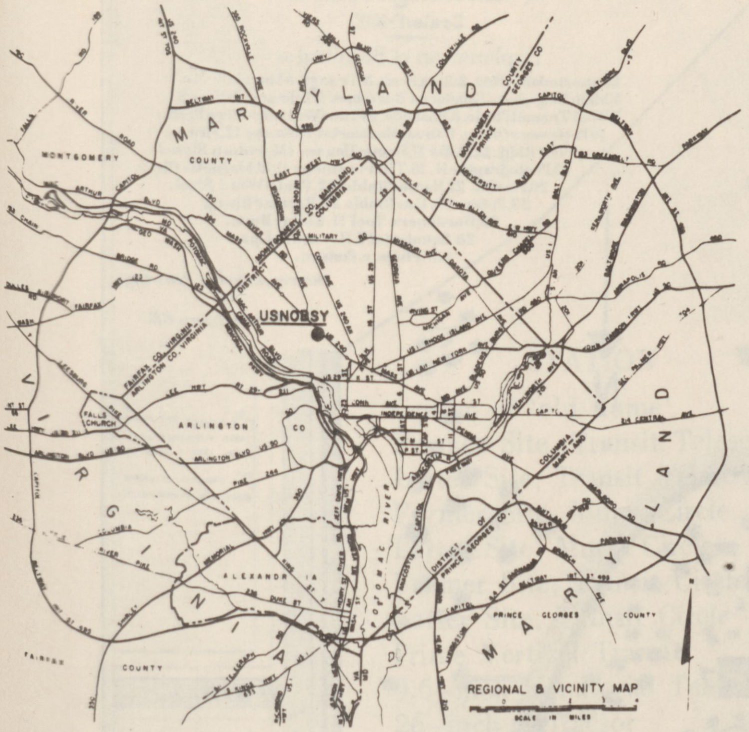

GEOID-ELLIPSOID RELATIONSHIPS
(Illustrating effects of irregular mass distribution in the earth's crust)
EARTH'S SURFACE
MOUNTAIN
GEOID UNDULATION
ELLIPSOID
MEAN SEA SURFACE
(GEOID)
OCEAN
GEOID
GEOID UNDULATION
OCEAN
PERPENDICULAR TO GEOID (PLUMBLINE)
PERPENDICULAR TO ELLIPSOID
DEFLECTION OF THE VERTICAL

FIGURE 1

(From [41])


TO WISCONSIN AVE
34TH ST
MASSACHUSETTS
RESIDENTIAL
CIRCLE
OBSERVATORY
DAVIS ST NW
ROCK CREEK PARK
AVENUE
BRITISH EMBASSY
CIRCLE
OBSERVATORY
DUMBARTON OAKS PARK
OBSERVATORY LANE
GOLDSBOROUGH
AVENUE
MAURY AVENUE
NEWCOMB
PLACE
1000 FT. RADIUS
PARKING LOT
200 CARS
73
62
21
19
20
37
43
74
27
38
29
85
69
40
39
10
75
76
82
2
28
8
16
72
45
68
61
78
30
55
60
83
84
54
59
70
52
77
46
56
MAG. NORTH
TRUE NORTH
MAG. DEC. 7°W
1960
100 50 0 100 200
SCALE IN FEET

Naval Observatory (new), Washington, D. C.


MARYLAND
MONTGOMERY COUNTY
USNOBSY
VIRGINIA
ARLINGTON CO
FALLS CHURCH
ALEXANDRIA
FAIRFAX COUNTY
POTOMAC RIVER
DISTRICT OF COLUMBIA
PRINCE GEORGES COUNTY
REGIONAL & VICINITY MAP
SCALE IN MILES

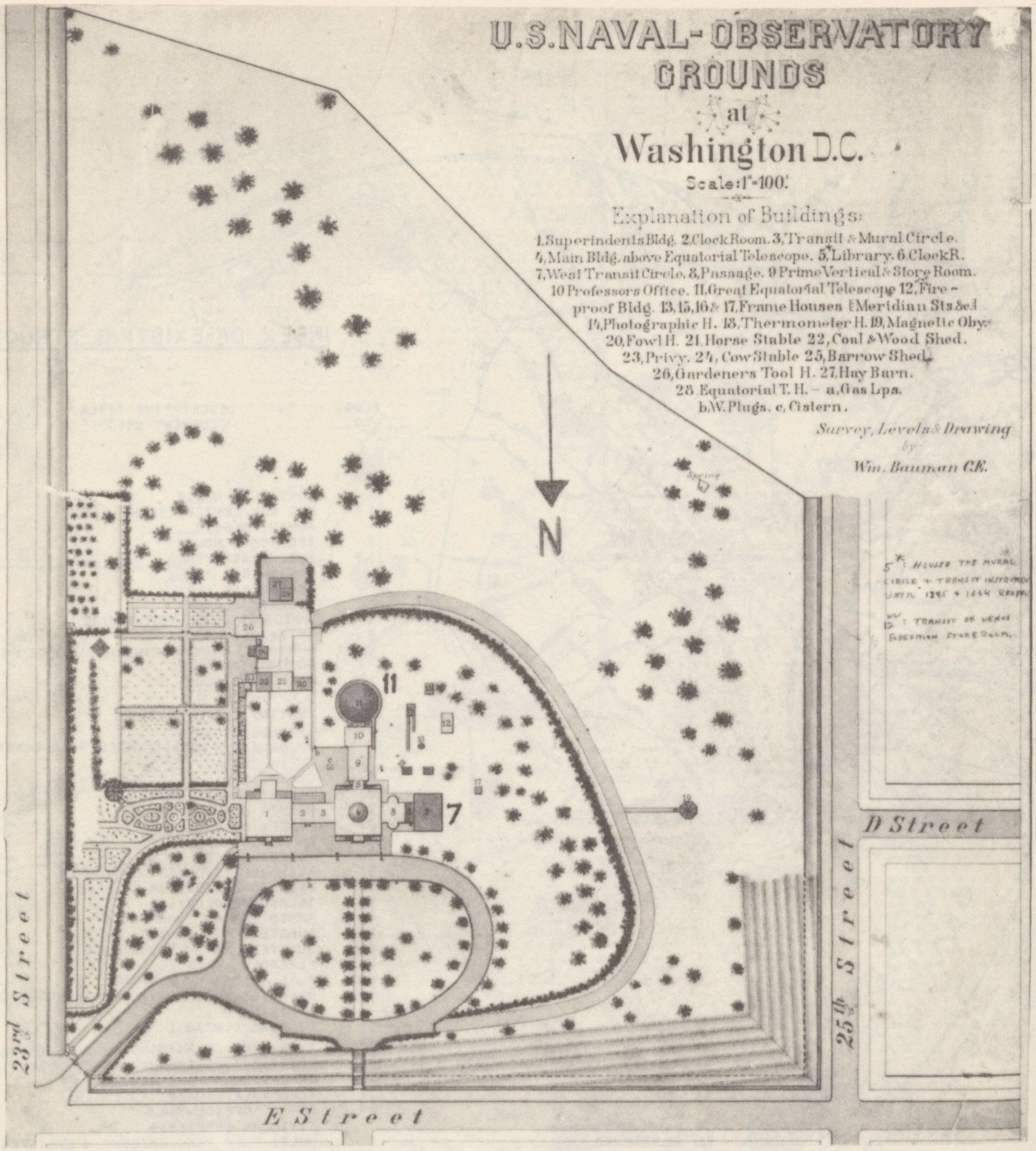
INDEX OF EXISTING STRUCTURES

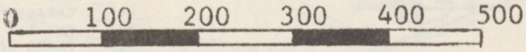
BLDG. NO.	DESCRIPTIVE TITLE (CURRENT USE)
A	ADMIRAL'S HOUSE
1 ×	RES REF CENTER (TECH. LIB)
	ADMIN. BLDG.
2	TELESCOPE HOUSE
3 ×	ELECT/MAINT/SHOP
	OBSERVER'S BLDG.
	OBSERVER'S BLDG.
	STORAGE/CLOCKS
6	AUTOMATIC TRANSIT HOUSE
7	6" TRANSIT HOUSE
8 ×	------NAVY-MARINE RESIDENCE FOUND
	ADMINISTRATION
10	ASTROLABE BLDG.
16 ×	A.O. USE
	HEATING PLT/OIL (2,842 SF)
19 ×	STORAGE/OTHER
	PW/GARAGE & MEQ(1000)(QTRS.A ANNEX)
20	GREENHOUSE
21	GREENHOUSE
25	TRANSIT LAB. (PORT)
27	MARKER HOUSE
28	MARKER HOUSE
29	MARKER HOUSE
30	MARKER HOUSE
37	FLAMMABLE STORAGE
38	TELESCOPE BLDG/LAB
39	TELESCOPE BLDG/LAB
40	PHOTO ZENITH TUBE HOUSE
43	QUARTERS "D" GARAGE
44	QUARTERS "B" & "C" GARAGE
45	FLAGPOLE
46	FUEL DISPERSING PUMP
52 ×	PW/MAINT SHOP NAVY OFF. WIVES FAC.
	ADMIN/R & D
	HEATING PLNT/OIL
54	TIME SERVICE ASTRONOMERS' BUILDING
55	PRECISE TIME SYNCHRONIZATION SERVICE
56	DEFENSE MAPPING AGENCY
58	FLAMMABLE STORAGE
59 ×	ADMIN. OFFICE/R&D
	CIVILIAN CAFETERIA
	MULTI-PURP TRNG RM/CONF & LECTURES
60	PW/MAINT SHOP
61	OBSERVER'S DORMITORY
62	GARAGE ANNEX (5 CAR)
64	GARAGE
68	ANT SYS N-T AID
69	PHOTO ZENITH TUBE HSE
70	TENNIS COURT
72	MOQ-QTRS. B & C
73	MOQ-QTRS. F & G
74	MOQ-QTRS. D
75	STORAGE/MAINT
76	STORAGE/MAINT
77	AIR COND PLNT
78 ×	N-T AIDS BLDG/O
	AST/GP/GR BLDG
	AST/GP/GR BLDG
80	GATE HOUSE
81	ANT SYS N-T AID
82	TRANSIT CIRCLE SUPPORT BLDG.
83	EMERGENCY GENERATOR BLDG.
84	HYDROGEN MASER BLDG.
85	TILTMETER INSTALLATION
86	ANT SYS N-T AID
87	TELESCOPE BLDG

NOTE :
STRUCTURES MARKED WITH AN ASTERISK - THUS × ARE MULTIPLE CATEGORY USE STRUCTURES.

LEGEND

LEGEND	EXISTING TO BE RETAINED
BUILDINGS & STRUCTURES	■
NAVY PROPERTY BOUNDARY WITHOUT FENCE	●———●
NAVY PROPERTY BOUNDARY WITH FENCE	●—x—●
ROADS, WALKS & PAVED AREAS	═══
FENCE	x———x
MAIN STATION ENTRANCE	➡
GATE	—⌒—

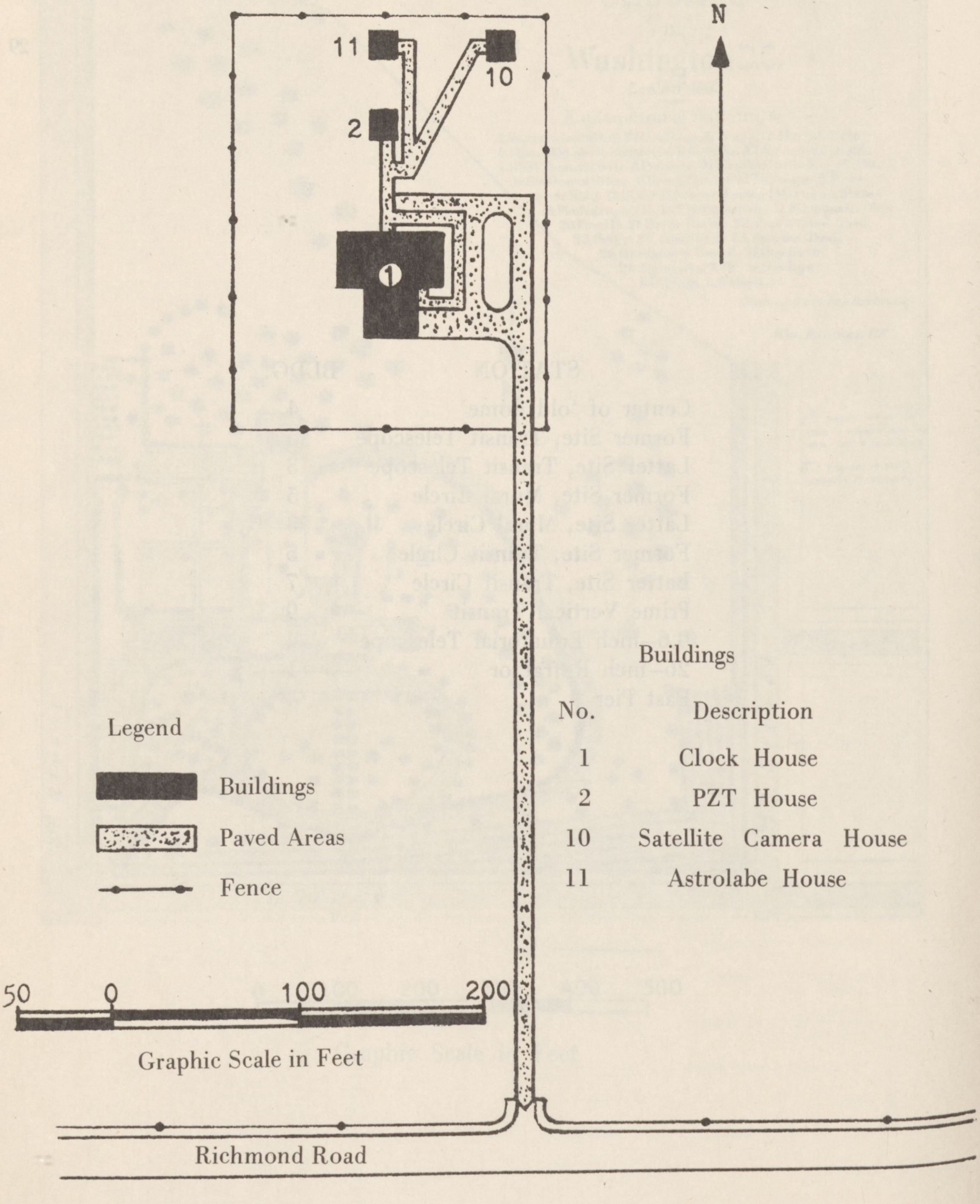

U.S. NAVAL-OBSERVATORY GROUNDS
at
Washington D.C.
Scale: 1"=100'.
Explanation of Buildings:
1, Superindents Bldg. 2, Clock Room. 3, Transit & Mural Circle.
4, Main Bldg. above Equatorial Telescope. 5*, Library. 6, Clock R.
7, West Transit Circle. 8, Passage. 9 Prime Vertical & Store Room.
10 Professors Office. 11, Great Equatorial Telescope 12, Fire-proof Bldg. 13, 15, 16 & 17, Frame Houses (Meridian Sts &c.)
14, Photographic H. 18, Thermometer H. 19, Magnetic Oby.
20, Fowl H. 21, Horse Stable 22, Coal & Wood Shed.
23, Privy. 24, Cow Stable 25, Barrow Shed.
26, Gardeners Tool H. 27, Hay Barn.
28 Equatorial T. H. – a, Gas Lps.
b, W. Plugs. c, Cistern.
Survey, Levels & Drawing by Wm. Bauman C.E.
5*: HOUSED THE MURAL CIRCLE + TRANSIT INSTRUMENT UNTIL 1845 + 1844 RESPEC
12**: TRANSIT OF VENUS EXPEDITION STORE ROOM.
N
Spring
11
7
D Street
25th Street
23rd Street
E Street


0
100
200
300
400
500

Graphic Scale in Feet

Naval Observatory (old), Washington, D.C.

STATION	BLDG.
Center of 'old dome'	4
Former Site, Transit Telescope	5
Latter Site, Transit Telescope	3
Former Site, Mural Circle	5
Latter Site, Mural Circle	3
Former Site, Transit Circle	5
Latter Site, Transit Circle	7
Prime Vertical Transit	9
9.6–inch Equatorial Telescope	4
26–inch Refractor	11
East Pier	4


N
11
10
2
1
50
0
100
200
Graphic Scale in Feet
Richmond Road

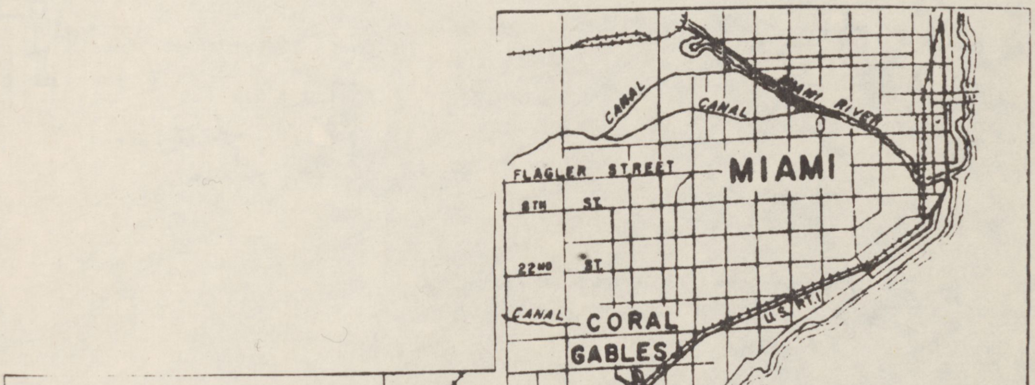
Legend

- ▆ Buildings
- ▨ Paved Areas
- —●— Fence

Buildings

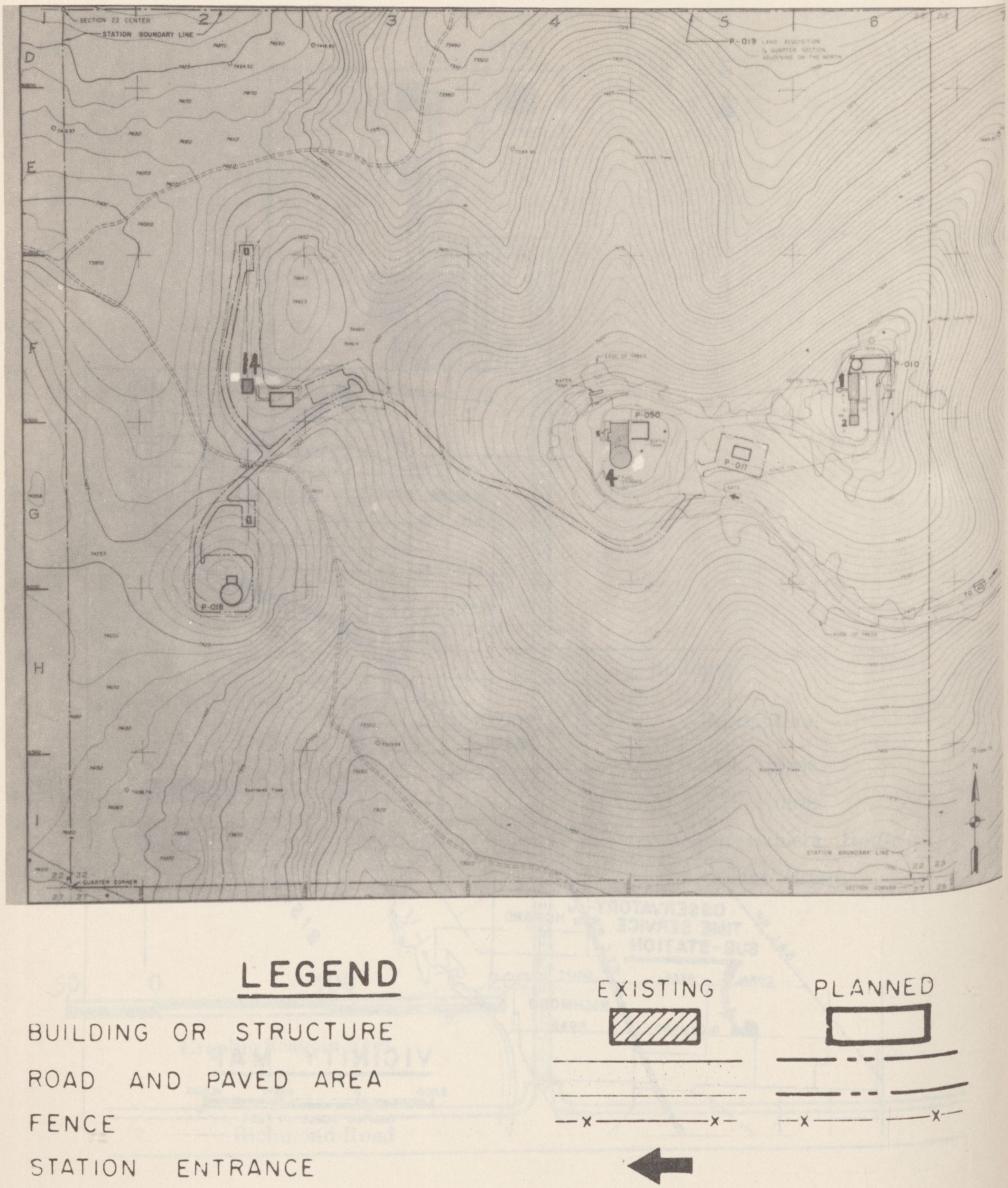
No.	Description
1	Clock House
2	PZT House
10	Satellite Camera House
11	Astrolabe House

NOTSS, Richmond, Fla.



VICINITY MAP

CANAL
CANAL
MIAMI RIVER
FLAGLER STREET
MIAMI
8TH ST.
22ND ST.
CANAL
CORAL GABLES
U.S. RT. 1
SNAPPER CR.
SOUTH MIAMI
S.A.L. R.R.
KENDALL
BISCAYNE BAY
N
NAVAL OBSERVATORY TIME SERVICE SUB-STATION
HOWARD
F.E.C. R.R.
U.S. RT. 1
CORAL REEF DRIVE
RICHMOND ROAD
RICHMOND
8,000
0
8,000
16,000
GRAPHIC SCALE IN FEET

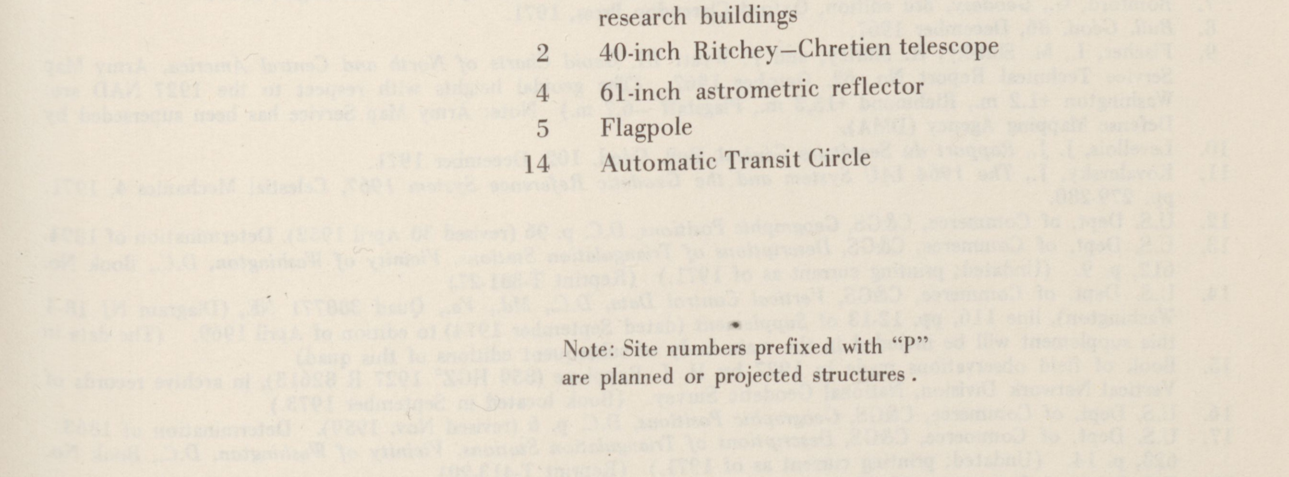

SECTION 22 CENTER
STATION BOUNDARY LINE
1
2
3
4
5
6
7
D
E
F
G
H
I
P-019 LAND ACQUISITION ¼ QUARTER SECTION ADJOINING ON THE NORTH
14
4
1
2
P-018
P-050
P-011
P-010
EDGE OF TREES
WATER TANK
Scattered Trees
N
QUARTER CORNER
SECTION CORNER
22
27
23
28
LEGEND
EXISTING
PLANNED
BUILDING OR STRUCTURE
ROAD AND PAVED AREA
FENCE
STATION ENTRANCE

USNO, Flagstaff, Ariz.

INDEX OF EXISTING STRUCTURES

No.	Description
1	24-inch reflector and adjoining research buildings
2	40-inch Ritchey–Chretien telescope
4	61-inch astrometric reflector
5	Flagpole
14	Automatic Transit Circle

Note: Site numbers prefixed with "P" are planned or projected structures.


T 21 N
TO WILLIAMS
40
66
89
15
14
13
R 6 E
R 7 E
18
17
LOWELL OBSERVATORY
CITY OF FLAGSTAFF
89
66
PRIVATE PROP.
P-019
22
23
24
19
20
40
STATE OWNED PROPERTY
ACCESS ROAD
79
89 A
NORTH
17
U S NAVAL OBSERVATORY
27
26
25
30
29
PRIV. PROP.
U S OF
DEPARTMENT AGRICULTURE
TO PRESCOTT
TO PHOENIX
GRAPHIC SCALE
0
1/2
2 Mi.
VICINITY MAP

On detailed map at left, boundary marks are at 500–foot intervals.

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23. *Ibid.,* p. 465.
24. *Ibid.,* p. 466.
25. U.S. Dept. of Commerce, C&GS, *Vertical Control Data, Florida,* Quad 250801 (Diagram NG 17-8 Miami), line 103, pp. 3 and 33, October 1969.
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